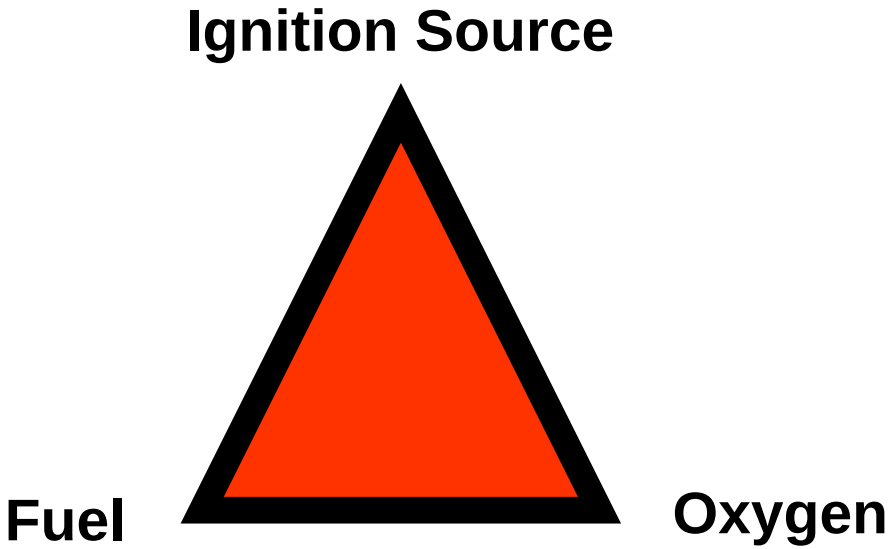
H_2 Training.

BMW Hydrogen 7- Safety.

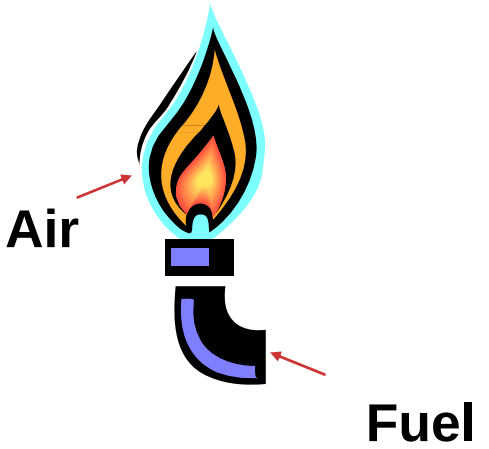
Safety Basics.
Combustion Triangle.



Lower Explosion Limit -> not enough fuel
Upper Explosion Limit -> too much fuel
Stoichiometric –> reaction of all fuel and all oxygen

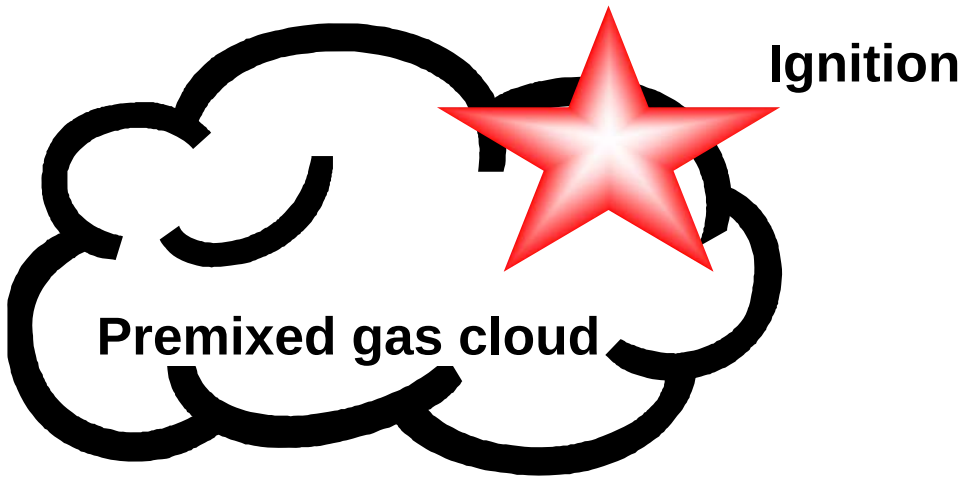
Safety Basics.
Fire and Explosion.

Fire



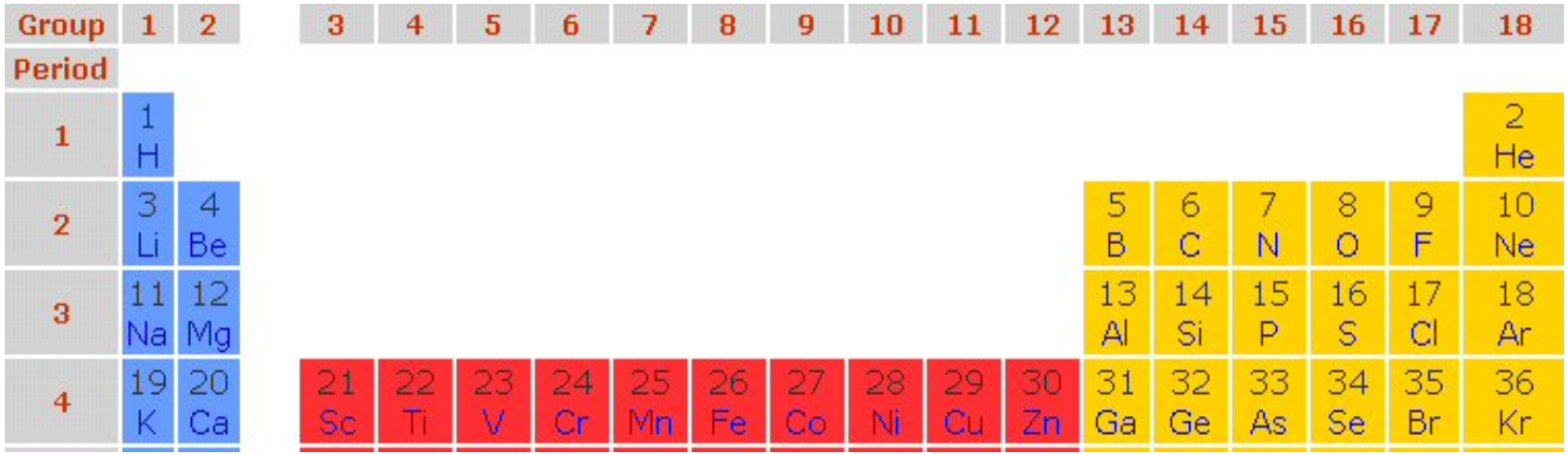
- continuous reaction
- locally limited release of energy

Explosion



- abruptly, rapid reaction
- primary: locally limited release of energy
  secondary: danger of
  Expansion of volume $V/V_0 = 8$ (p=k)
  Increase of pressure $p/p_0 = 8$ (v=k.)

Hydrogen as a carrier of energy.
Main Physical Properties.



- Smallest and Lightest
- Low Volumetric Energy Density
- Highest Specific Energy

Hydrogen as a carrier of energy.
Comparison between Hydrogen and Gasoline.

Safety-specific properties of hydrogen, methane and petrol				
Characteristics ✓		Hydrogen	Methane (natural gas)	Petrol
Lower calorific value	(kWs/g)	120	50	44.5
Self-ignition temperature	(°C)	585	540	228–501
Flame temperature	(°C)	2,045	1,875	2,200
Ignition limits in air	(Vol.–%)	4–75	5.3–15	1.0–7.6
Minimum ignition energy	(mWs)	0.02	0.29	0.24
Combustion speed in air (stochiometric mixture)	(cm/s)	265	40	40
Detonation limits	(Vol.–%)	13–65	6.3–13.5	1.1–3.3
Detonation speed	(km/s)	1.48–2.15	1.39–1.64	1.4–1.7
Theoretical explosion energy	(kg TNT/m³ Gas)	2.02	7.03	44.22
Diffusion coefficient in air	(cm²/s)	0.61	0.16	0.05

Safety.
Hydrogen Detection.

Hydrogen cannot be detected by human senses!

It has:

- **no** smell
- **no** color
- **no** taste
- **no** flavor

We use therefore when required a H2 detector device: MS-Tox.

Safety.
Hydrogen Flame.

Flame Detection:

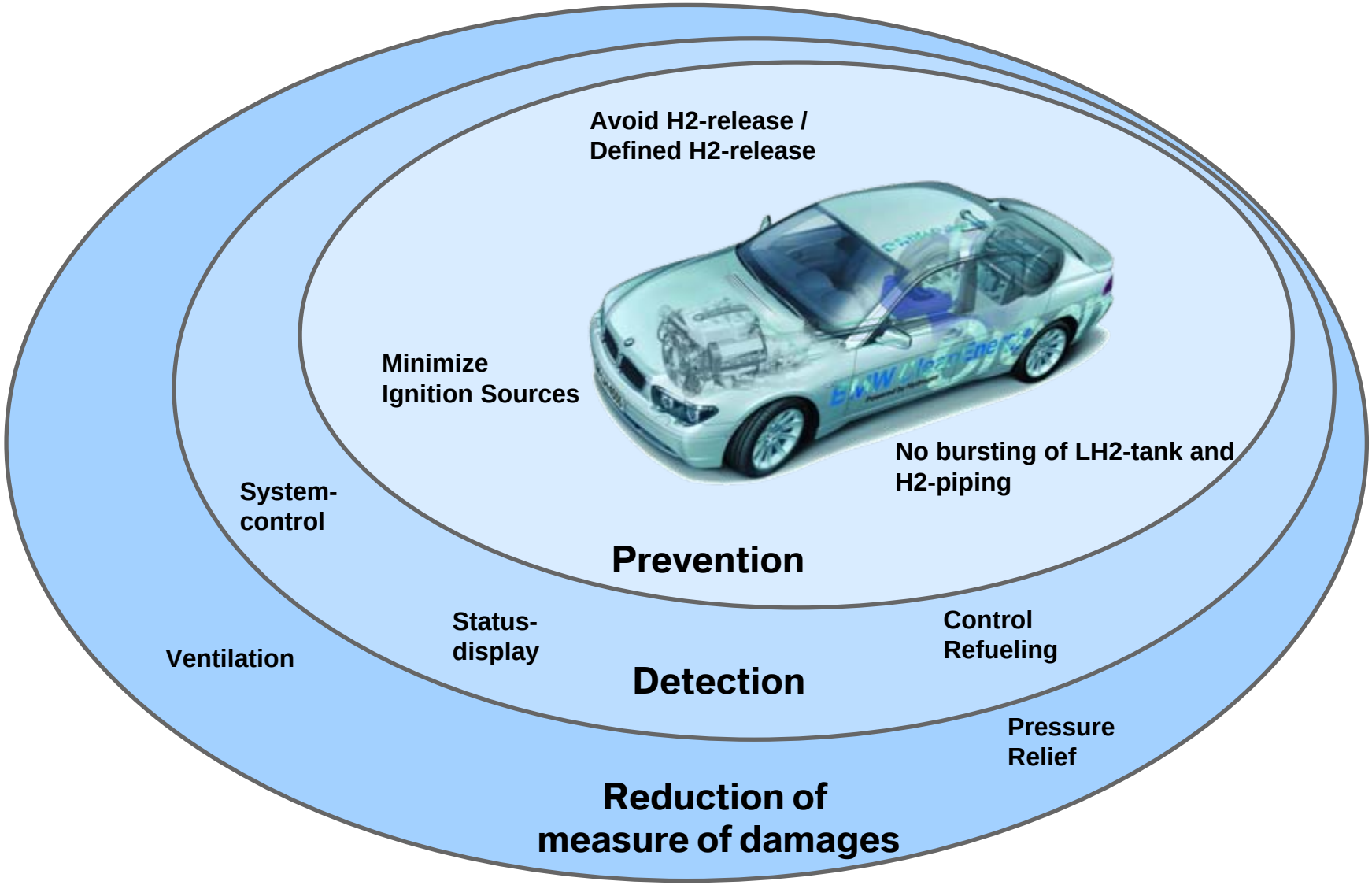
- Hydrogen/Air – mixture:
  Flame during day time is **practically invisible**
  (one can detect the air shimmering)
- Hydrogen/Oxygen – mixture:
  Flame is **invisible**

Development Targets.
Safety Requirements.

1. No uncontrolled release of hydrogen, especially no bursting of the tank, the piping and components
2. No formation of an ignitable mixture in the vehicle
3. No uncontrolled ignition of a hydrogen/air mixture
4. No release of hydrogen in critical concentrations within confined spaces

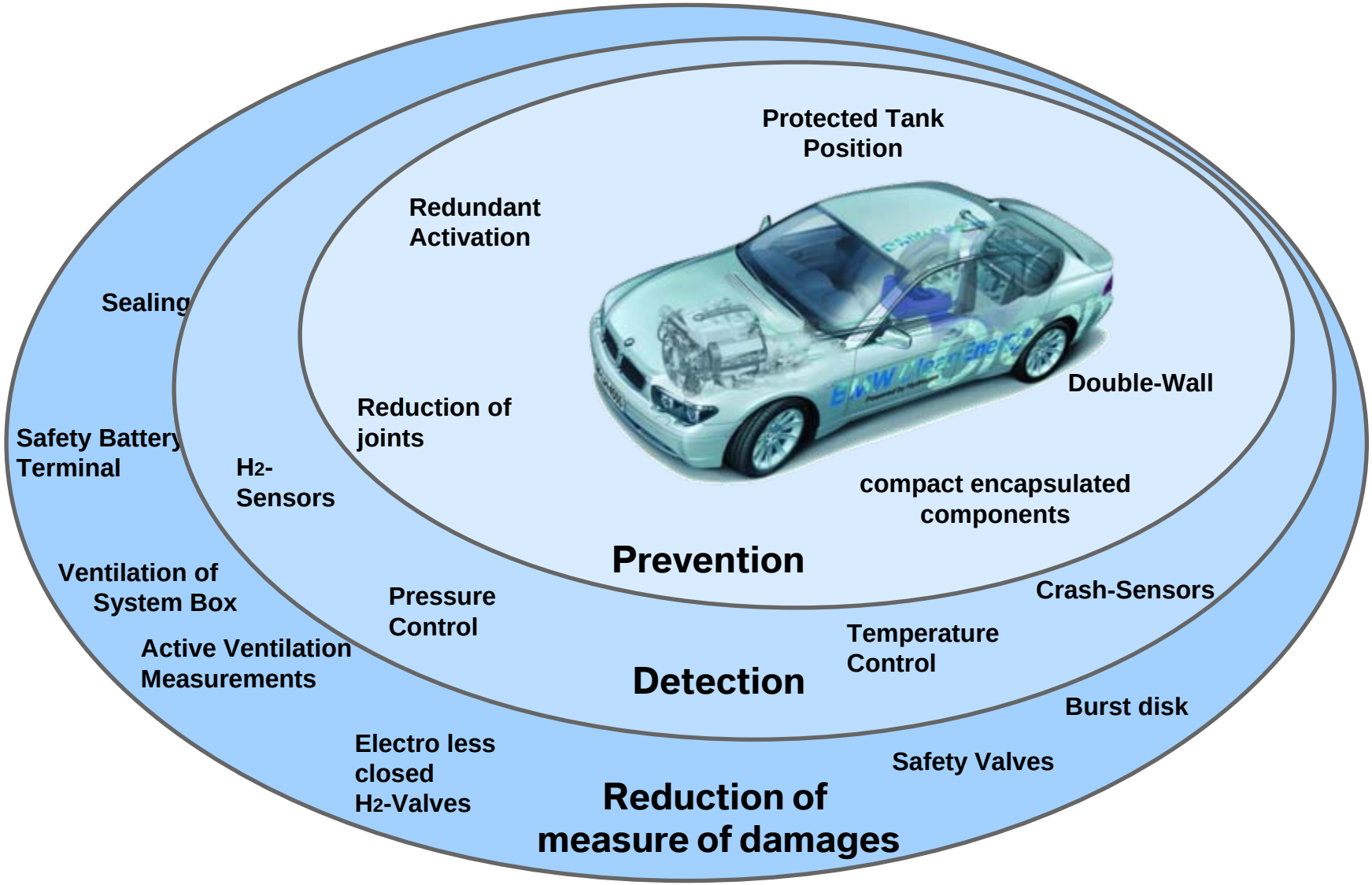
This safety targets have to be fulfilled by the vehicle autonomously!

Safety Concept.
”Shell” Model.

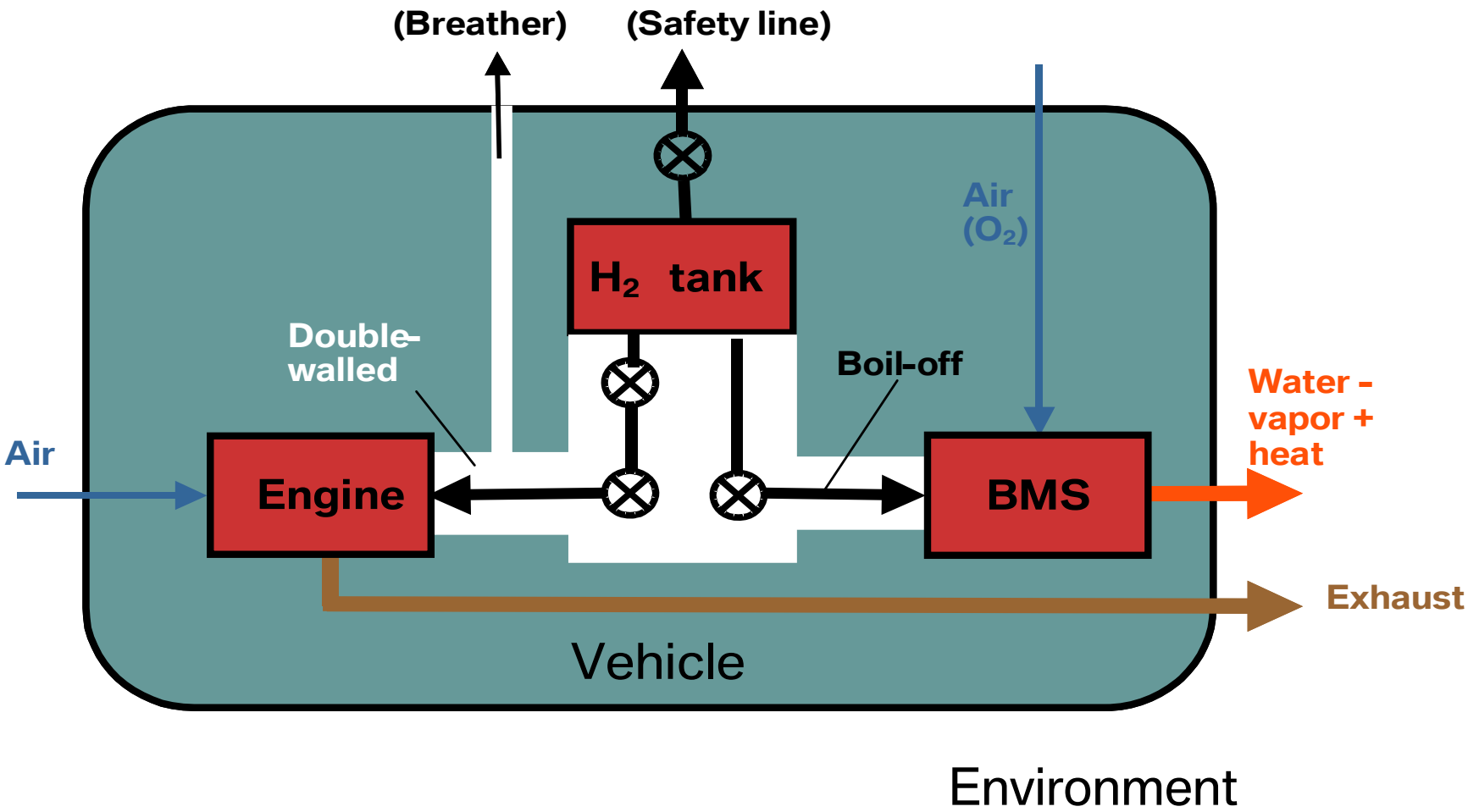


“Shell” Model.

Safety Measures in Detail: Implementation

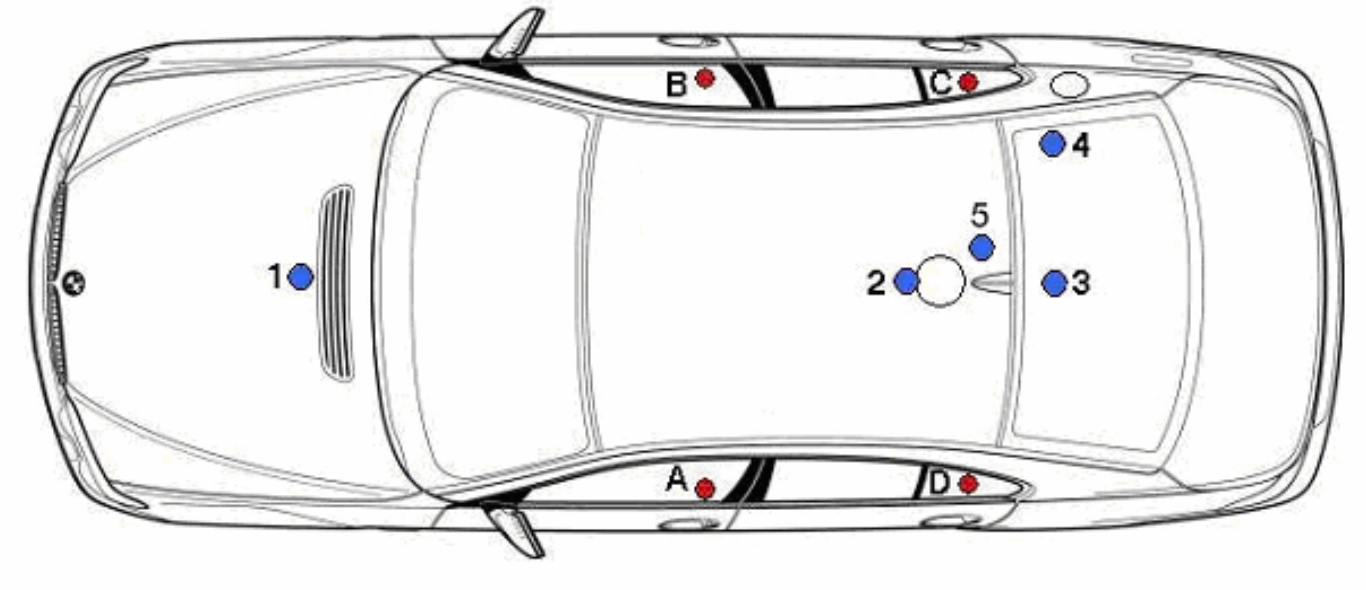


Safety Concept.
Double-walled H_2-piping.



Safety Concept.

Gas-warning and H_2-detection.

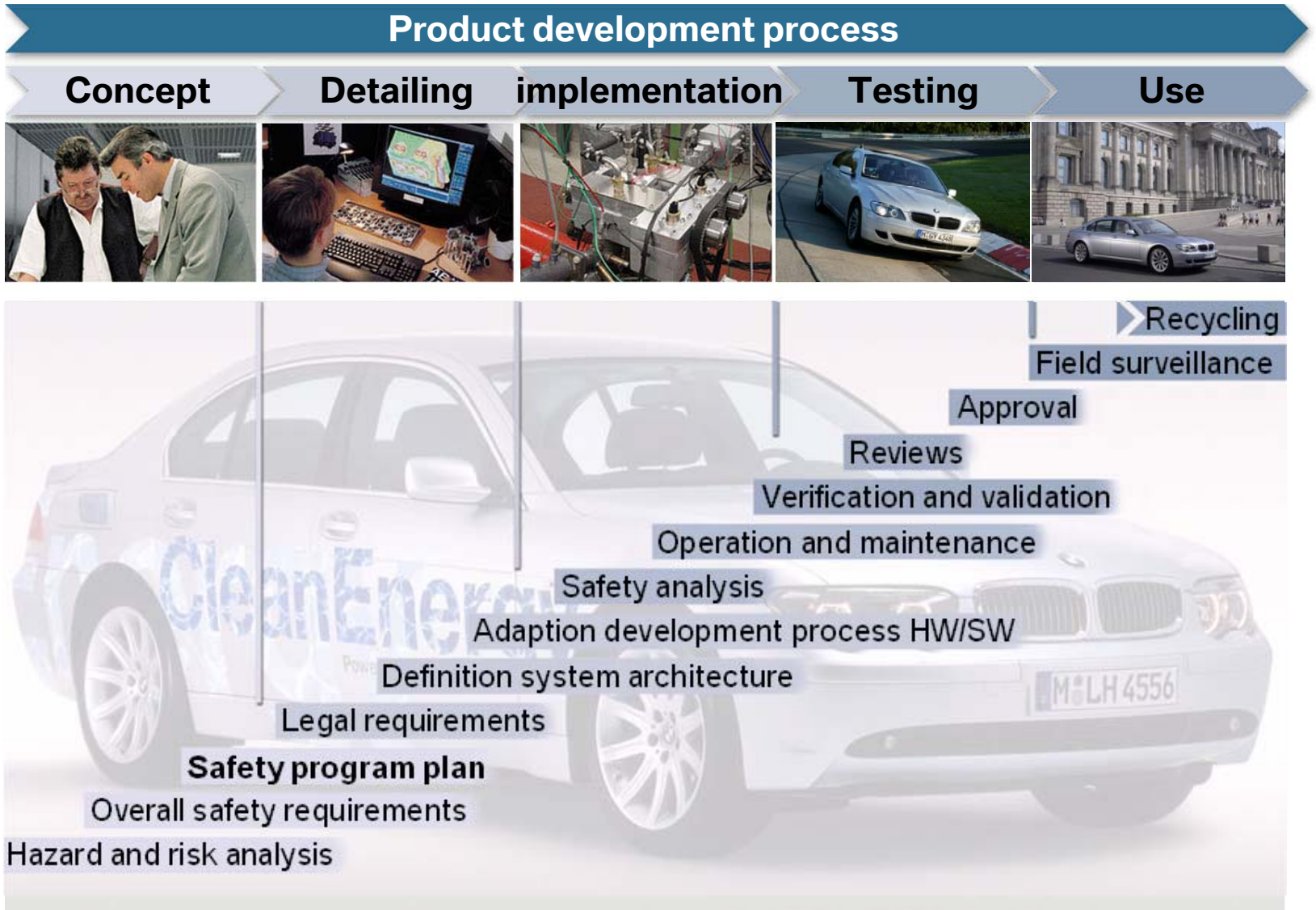


1..... Engine
2..... Interior
3..... Trunk
4..... Coupling
5..... Double housing

A-D: 4 time red flashing LED's in the door
if hydrogen is detected at a H_2-concentration of 2% Volume

Functional Safety Process.

Safety process at BMW.



BMW Hydrogen 7.
System- and components-testing.

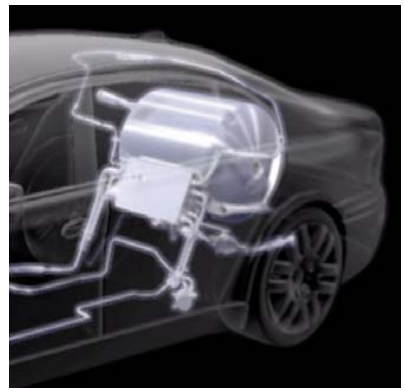
Hydrogen 7.
Passive Safety.

Level 1 – BMW-Group standard Crash tests

- „crash-safe“ Package
- no tank deformation
- H_2-feed-lines endure deformation

Level 2 – Loss of Tank Insulation

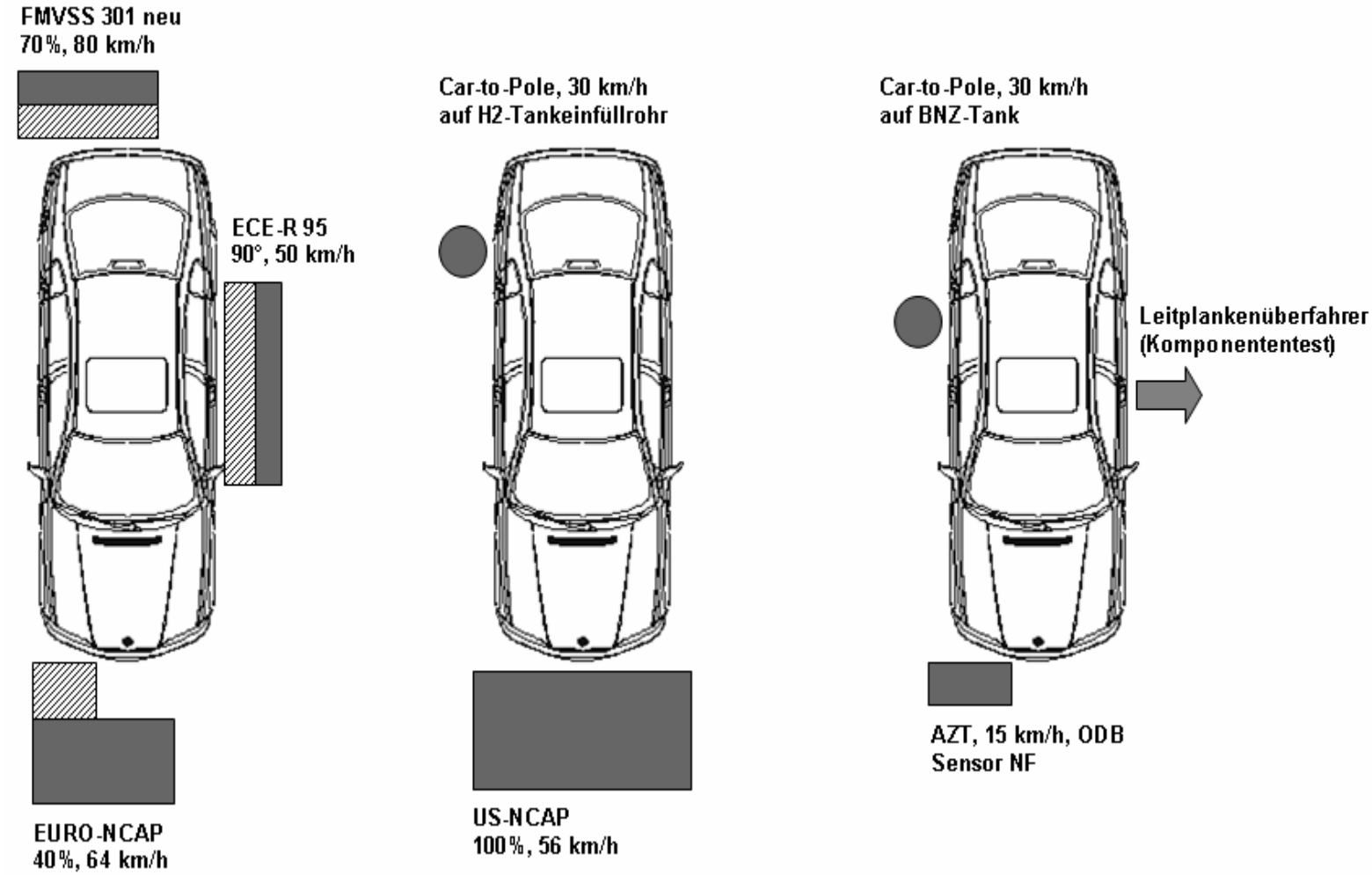
- H_2-release through the Safety valves



Level 3 – Worst Case Analysis

- despite tank-damage no burst
- H_2 escapes upwards
- no Explosion

Hydrogen 7 – Passive Safety.
Level 1 – Crash Tests.



Crash Tests.
US FMVSS301, 70% Offset.

Target

LH_2-System shuts off into safe status and remains tight.

Result

- H_2-Valves closed
- no loss of vacuum insulation
- H_2-system tight

Crash Tests.
Car-to-Pole on LH_2-Filling System.

D=250mm, 30 km/h

Target

LH2-System shuts off into safe status and remains tight.

Result

- H_2-Valves closed
- no loss of vacuum insulation
- H_2-system tight

Crash at the Limit.
Truck running over.

Barrier hight: 700 mm, 70 km/h (EES=45 km/h)

Target

Controlled release of H_2

Result

- H_2-Valves closed
- no loss of vacuum insulation
- H_2-system tight

BMW Hydrogen 7.
Overview testing.

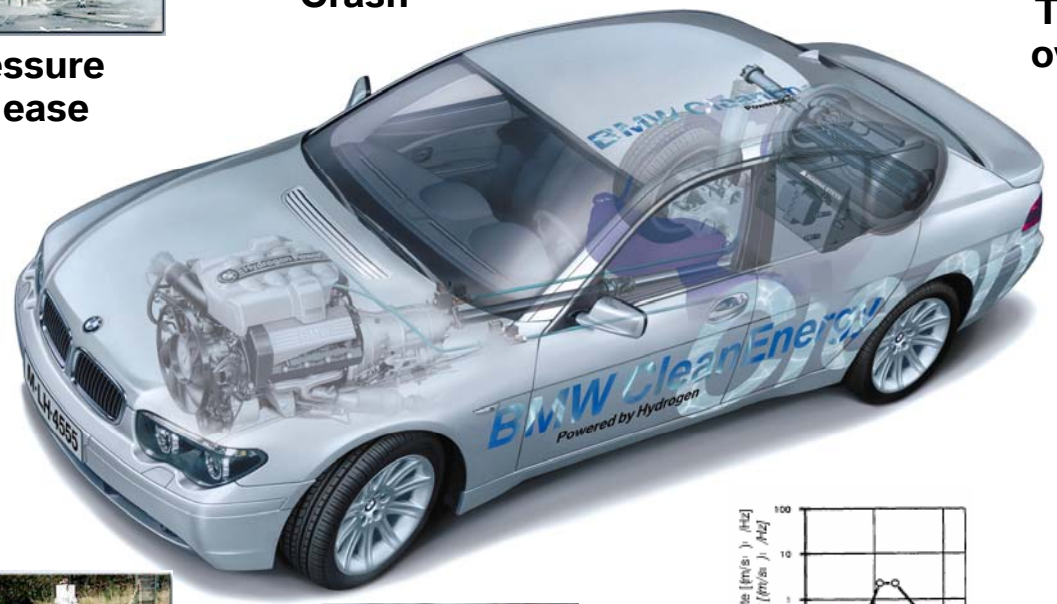
Pressure release

Crash

Roll-Over

Thermal overload

Gas flow

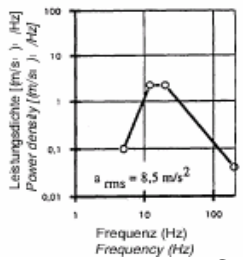


Explosion in system box (double housing)

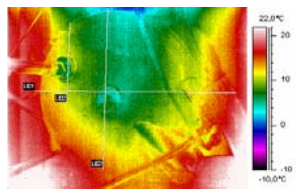
Explosion tests

Mechanical damage

Rupture of the vacuum



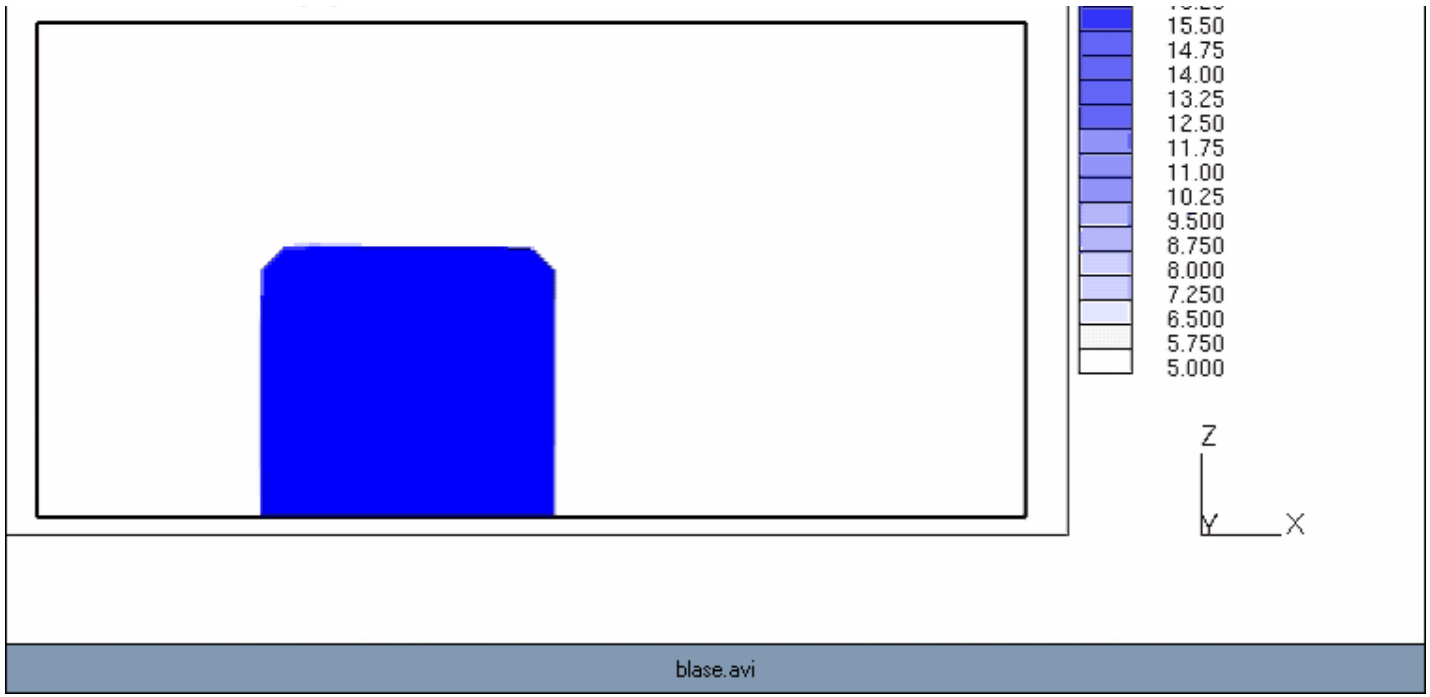
Integrity of operation



Thermograph LH_2-Tank

H_2-release in a garage.
Deployment of a local cloud.

A 100% H2-cloud is released in a hermetic closed room.



Hydrogen Workshop Eching.

Controlled Release of Hydrogen.

H2 Training.
BMW Hydrogen 7 - Safety.

Validation of Hydrogen 7.
Safety verification during the refueling.

Car-conditions

- Gear in P-position.
- Park-brake.
- Ignition for radio.
- no H_2-gas detected.
- no crash signal.

Error detection during refueling

- Overpressure
- Over-fueling
- H_2-Alarm

Results:

- Safety functions work well.
- The refueling is aborted.